unexcited nerve-fibres which surround the active fibres near the proximal end, shunts part of the current.

This curve should be compared with No. 1535 in fig. 14, in which the wave of electrical response is *longer* than the distance between the leads, and consequently the first phase is due entirely to the development, and the second to the subsidence, of the E.M.F.

The material discussed in this paper consists mainly of some 1900 photographs of the electrical response of nerve, taken in the Physiological Laboratory, Oxford, by Professor Gotch and myself. I have made full analyses of more than 150 of the curves, and have measured the principal points of a much larger number.

Many other examples could be given, but I have in each case selected the one best suited, either from the sharpness of the definition or the completeness of the data, to illustrate the theory. It has become evident from a comparison of the photographs, that the values of v, θ, π, and $k\pi$, are greatly affected by temperature and the condition of the preparation; but as these involve the physiological side of the problem, which will be dealt with by Professor Gotch, I have for the present confined myself to showing the methods by which they may be determined.

"Contributions to a Theory of the Capillary Electrometer. I.—On the Insulation Resistance of the Capillary Electrometer, and the Minimum Quantity of Electricity required to produce a Visible Excursion." By GEORGE J. BURCH, M.A. Oxon., F.R.S., Lecturer in Physics, Reading College, Reading. Received April 17,—Read May 1, 1902.

What may be called the Insulation Resistance of the capillary electrometer is important for two reasons—first, as to its bearing on the theory of the instrument, and secondly, as affecting the method of using it in dealing with electrical charges or quantities of limited amount. I propose briefly to record some of my own experiments on this head.

In many capillary electrometers, if an excursion of the meniscus is produced by touching the terminals with a source of electromotive force and then removing it, leaving the circuit open, the meniscus returns in a comparatively short time to the position it would occupy if the instrument were short circuited. In other words, the charge, which, as Lippmann showed, is contained in the instrument as long as the meniscus is deflected from its zero position, gradually leaks away. The question naturally arises, whether this leakage is accidental like

that of a gold-leaf electroscope, or essential, in the sense that some small current may be necessary to maintain a deflection. Lippmann, in his original thesis, did not mention any direct experimental investigation of this problem, though his whole mathematical argument is in accordance with the supposition, that no current is required to maintain a deflection. I therefore began my practical examination of the properties of the capillary electrometer in January, 1887, with this experiment. I made a quick-acting electrometer, carefully insulating its parts with freshly cut soft rubber, and joined it up in series with a very sensitive galvanometer in the derived circuit of a potentiometer. Both instruments were furnished with short-circuiting keys. On opening the electrometer key, there was a large excursion of the meniscus. As soon as it had come to rest in its new position under the action of the electromotive force, the galvanometer short-circuiting key was opened. There was no deflection. But any thing that caused the meniscus to *move*—whether a slight change in the pressure on the mercury, or a small movement of the rider of the potentiometer, produced a large or even violent, but always temporary, deflection of the galvanometer.*

I found afterwards that Fleischl had obtained similar results in 1879.

The converse of this experiment is specifically referred to by Lippmann. If a charge is communicated to an electrometer by rubbing the terminals with the finger, and the circuit is left open, the mercury returns to its zero point very much more slowly than if the circuit is closed. And I found that by careful attention to the insulation the capillary electrometer could be made to hold a charge quite as long as a gold-leaf electroscope. Thus another instrument made a few weeks later was left charged with the circuit open, and "no change in the deflection could be detected after 35 minutes."

The most remarkable experiment of this kind was made unintentionally. In June, 1898, I made a new projection electrometer for the work on the electromotive properties of nerve in which Professor Gotch and I are engaged at Oxford. This instrument is the most rapid and sensitive that I have ever employed, and it is still in use. It is a modification of that figured in my book.† The capillary, which points vertically downwards, is contained in a glass trough about $\frac{1}{2}$ mm. wide and 25 mm. long, formed by grinding away the front of a thick-walled tube so as to lay open the bore from end to end. This trough is closed in front by a piece of glass, and its lower end dips into

* A galvanometer by Elliott, of 25,500 ohms resistance. The current given by one Daniell cell through a resistance of 63,900 megohms produces a deflection of one scale-division, according to the maker's certificate.

† "The Capillary Electrometer in Theory and Practice," reprinted from the 'Electrician,' 1896.

dilute sulphuric acid, the surface tension of which causes it to fill the trough to its upper end. The acid is contained in a U-tube, the bend of which is filled with mercury. Two platinum wires, dipping respectively into the mercury in the U-tube and that in the capillary, serve to connect the electrometer with the experimental circuit. A few weeks after it was set up, it was accidentally left, charged to about 0·025 volt, with the circuit open from 1 P.M. on Saturday to 10.30 A.M. on Monday. The image of the meniscus was still, as it had been left $45\frac{1}{2}$ hours before, between two reference lines on the screen corresponding to a difference of potential of 0·0008 volt, so that this represents the maximum loss, and as the zero-position had not altered, at least 97 per cent. of the original charge still remained in the electrometer. And as the circuit included no less than seven keys and switches and about 23 metres of wire, it is probable that the instrument was not responsible for all the leakage. Inasmuch as it might be objected that the mercury had stuck in the tube and so maintained its position before closing the circuit, I waved an electrified ebonite tube to and fro near one of the terminals. This causes the meniscus to move up and down by induction exactly as it would cause the gold leaves of a charged electroscope to diverge more widely or collapse. But just as the gold leaves would remain divergent after the final removal of the ebonite at the same angle as when they were first charged, so the meniscus when the ebonite is taken away returns to the position it had assumed in virtue of the original charge put into it, always supposing that no sparks have been allowed to pass. This method is extremely useful in guarding against false readings due to a sticky tube.

I have verified this result several times since by observations extending over 5 or 6 hours, but I have not cared to risk leaving the key open during my absence from the room.

After a lapse of nearly four years the insulation resistance is naturally less, but it varies greatly with the weather. The easiest way of making comparative measurements is to observe the time required for any charge to fall to half its initial difference of potential. This I shall refer to briefly as the "time of half-discharge," and it answers to the "time constant" of a condenser, but is simpler to use in practice, as it is easier to divide a number by 2 than by 2·71828, and also to observe deflections consisting of a whole number of scale divisions.

On March 27th of this year, the time of half-discharge was 13 minutes. On April 14th, just before rain, the weather having suddenly become warmer, the time of half-discharge was only 65 seconds. This is an exceptionally low value. A gold-leaf electroscope in the same room could not be made to retain a charge for 10 seconds.

In dry weather the electrometer responds so readily to frictional charges that the greatest care has to be taken to avoid touching the table with the sleeve or coat, lest the mercury should be driven out at the tip of the capillary.

The cause of the leakage is obviously two-fold. Part of it is external, as is evident from the marked influence of the weather. The capillary electrometer is necessarily a difficult instrument to insulate. Glass is under the most favourable circumstances liable to attract moisture in a rising temperature, and it becomes still more so when a portion of its surface is in contact with sulphuric acid diluted to such an extent. Varnish cannot be used, but I have thought vaseline round the ends of the tubes diminishes the leakage.

The other part of the leakage is internal. The cause of it is easily explained. The acid wets the glass and the mercury does not. There is therefore a tendency for the acid to insinuate itself between the mercury and the walls of the capillary. That it does so is evident on examining the mercury column under the microscope by front light with a high power. A film of liquid can be seen between the metal and the glass, and traced for some distance. When a short column of mercury 2 or 3 cm. long is used, this film soon passes right up the tube, and in a few weeks acid can be seen above the mercury. Even in the U-tube, where the mercury is beneath the acid, the same action takes place, though less rapidly. For this reason I prefer to have a depth of 8 or 10 cm. of mercury in the capillary, and 5 cm. in the U-tube. The internal leakage is least when the electrometer is new. Instruments which leak badly generally also "creep," *i.e.*, if left on open circuit the mercury does not remain at zero, but creeps slowly up or down, owing to some electomotive force within the instrument.

It seems at first sight inconceivable that there should be no current through a circuit consisting of platinum—mercury—dilute sulphuric acid—mercury—platinum, all of which are good conductors. Yet we have this fact: the time of half-charge of a quick electrometer is of the order of $\frac{1}{50}$ second, but the time of half-discharge of the same instrument on open circuit may be counted by days. The resistance to the passage of the current is manifestly not ohmic, but some effect produced at the interfaces between mercury and dilute acid.

The conditions suggest the counter electromotive force of polarisation, and here we are met by the experiments of Bouty, showing that the sum of the electromotive forces of polarisation at the two electrodes is always less than the applied electromotive force, no matter how weak it may be, so that there is always a permanent current through the electrolyte.

The explanation is I believe to be found in the fact that we are dealing with an interface between two liquids which cannot diffuse into each other, and that the electrical and chemical as well as

mechanical stresses are in some way distributed evenly over the whole area of contact; so that local action, to which perhaps we should ascribe the permanent current through the electrolyte with solid electrodes observed by Bouty, is prevented. I have already published my opinion that there is no electrolysis, properly so called, in a well-made electrometer.

A point of practical interest arises in connection with the rapid leakage of the charge in damp weather. How far does this defective insulation affect the records obtained with the apparatus? Taking the worst conditions, namely, when the time of half-discharge was 65 seconds, and the severest test, namely, photographing the discharge of a small Leyden jar charged to half a volt into the electrometer, we have the following data: The passage of the sensitive plate occupies 0·1 second, *i.e.*, $\frac{1}{650}$ of the time of half-discharge. A simple calculation will show that the total loss of charge in 0·1 second would be about one-tenth per cent., and as such a record would be completed in less than 0·01 second, the difference would be quite inappreciable.

It may be of interest to give some data as to the quantity of electricity which an electrometer will detect.

I took an ordinary gold-leaf electroscope with a brass knob 1 inch in diameter, and charged it so that the leaves diverged at an angle of about 20°. I then touched one of the terminals of the electrometer with the knob of the electroscope—the mercury instantly shot right out of the field. I then tried smaller charges, and found that a permanent excursion of fully 1 cm. was caused by a charge that produced a barely visible divergence of the gold leaves.

In order to measure the minimum quantity of electricity required to cause a visible movement of the meniscus, I earthed one pole of a four-cell accumulator, and touched the other with an insulated brass ball 3·3 cm. diameter, freshly polished, but not lacquered. On touching one of the terminals of the electrometer with the ball thus charged, there was a sudden upward jerk of the meniscus, not followed by any return. After six such charges, the level of the image of the meniscus had risen fully 1 mm. On reversing the charges on the sphere, the direction of the movement of the meniscus was reversed. With 4 volts the excursions were smaller, but well marked, and with 2 volts they were just visible. The total quantity of the charge therefore was $\frac{3 \cdot 3}{2} \times \frac{2}{300} = 0 \cdot 011$ electrostatic unit. But as the screen on which the excursions were observed was placed 81 cm. from the lens, whereas the photographs are taken at a distance of 126 cm., and as details are discernible on the photographs with a lens that are quite invisible to the naked eye, it may be safely said that a quantity equal to $\frac{1}{100}$ electrostatic unit will produce a measurable excursion.

The capacity of this electrometer, measured by the method of mix-

tures of Lord Kelvin, using a standard microfarad condenser, and employing the electrometer itself as indicator, is 0·363 microfarad at the part used in this experiment.

"On a Peculiarity of the Cerebral Commissures in certain Marsupialia, not hitherto recognised as a Distinctive Feature of the Diprotodontia." By G. ELLIOT SMITH, M.D., Ch.M., Professor of Anatomy, Egyptian Government School of Medicine, Cairo, and Fellow of St. John's College, Cambridge. Communicated by Professor G. B. HOWES, F.R.S. Received March 5,—Read March 20, 1902.

It has been known for a considerable time that some of the fibres of the ventral commissure of the cerebrum in certain Marsupials dissociate themselves from the rest of the commissure as soon as they have crossed the mesial plane; and that, instead of passing bodily into the *external* capsule, which is the usual course of the fibres of the ventral or anterior commissure, they form an aberrant bundle which associates itself with the *internal* capsule so as to reach the dorsal area of the neopallium by a shorter and slightly less circuitous course (fig. 2).

This peculiarity was represented in the drawings of sections through the brains of *Macropus* and *Phascolomys*, in 1865, by the late W. H. Flower.* It was more distinctly shown in a diagram† illustrating a coronal section through the brain of a Derbian Wallaby which was published 27 years later by Johnson Symington. Two years later I placed on record the observation upon it, that "in *Phalangista* [*Trichosurus vulpecula*] a bundle of anterior commissure fibres proceeds to the cortex *viâ* the internal capsule, in addition to the external capsule,"‡ and in the same place noted an analogous arrangement in various species of *Macropus*.

In 1897 Theodor Ziehen recorded§ the presence of such fibres in *Macropus*, *Aepyprymnus*, and *Phascolarctus*; but, like Flower and Symington before him, he did not venture on any explanation of them.

* "On the Commissures of the Cerebral Hemispheres of the Marsupialia and Monotremata, as compared with those of the Placental Mammals," 'Phil. Trans.,' vol. 155 (1865), p. 633.

† "The Cerebral Commissures in the Marsupialia and Monotremata," 'Journal of Anatomy and Physiology,' vol. 27, 1892, fig. 3, p. 81.

‡ "Preliminary Observations on the Cerebral Commissures," 'Proc. Linn. Soc. of N.S.W.,' 1894, pp. 647—648.

§ "Das Centralnervensystem d. Monotremen und Marsupialia (Semon's Zoologische Forschungs-Reisen in Australien)," 'Denkschr. Medic.-naturwis. Gesellsch. Jena,' vol. 6, Lf. II and IV, 1897—1901.